Quantify Lateral Dispersion and Turbulent Mixing by Spatial Array of χ-EM-APEX Floats

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LONG-TERM GOALS

Our long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes—i.e., internal tides, inertial waves, nonlinear internal waves, vortical modes, and turbulence mixing—in the ocean and thereby help develop improved parameterizations of mixing for ocean models. Mixing within the stratified ocean is a particular focus as the complex interplay of internal waves from a variety of sources and turbulence makes this a current locus of uncertainty. Our focus is on observing processes that lead to lateral mixing of water properties.

OBJECTIVES

Our primary scientific objective is to improve our understanding and parameterization schemes of small- to submeso-scale oceanic processes. Dispersion due to lateral processes with vertical and horizontal shears could enhance turbulent mixing. Both internal waves and vortical motions exist at vertical scales smaller than order of 10 m and horizontal scales smaller than few km. They have distinct kinematics and dynamics. Internal waves propagate and may carry energy to remote regions before they break and dissipate via turbulent processes, whereas vortical motions do not propagate and are often long lived. Separation of these two motions is necessary to improve parameterization schemes.

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APPROACH

We operated an array of EM-APEX floats, manufactured by Webb Research Corp, with some modifications by our group. In particular, 10 floats were modified to operate with dual, high-frequency-response thermistors. These were used to determine ocean turbulence levels on the upward traverses of the floats. The modified EM-APEX float is shown in Fig. 1.

Fig. 1(a): EM-APEX float with Chi sensors with white plastic covers behind blue guard.

Fig. 1 (b): About half the EM-APEX floats in the R/V Endeavor main lab.

Our approach was to measure the internal wave background, shear vector, vorticity vector, and turbulent mixing using a "swarm" of EM-APEX profiling floats that will profile simultaneously through the surface mixed layer and upper seasonal pycnocline every hour (Fig. 2). These 3-D observations of turbulence, instability, and small-scale processes are vital to understanding the dynamics of the coupling between the diapycnal mixing and oceanic lateral processes. Our primary purposes are to quantify the time evolution of the complete horizontal and vertical structures of turbulence mixing and shear instability including thermal diffusion rate χ, vertical shear S, stratification N, shear instability gradient Richardson number Ri, Ertel's potential vorticity Π, and effective horizontal eddy diffusivity k_h on isopycnal surfaces from shear dispersion, and to quantify effects of internal waves and vortical modes on horizontal dispersion and diapycnal mixing.

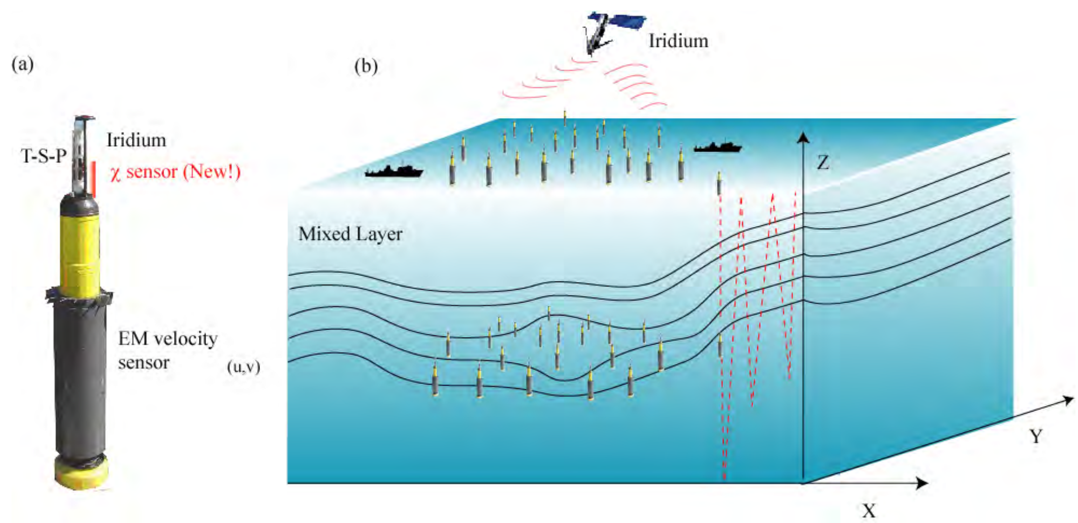

Fig. 2: (a) EM-APEX float with the proposed χ sensor. (b) Schematic of the experimental with a spatial array of 10 standard and 10-microstructure EM-APEX floats (χ-EM-APEX floats). N.B. The χ sensor is mounted so as to be out of the wake produced by the Iridium antenna, which is tilted to the side in the so-called "Mai Tai" mounting.

A suite of 21 EM-APEX floats was loaded on the R/V *Endeavor* over Memorial Day weekend in Morehead City, NC. The ship departed Morehead City at 0900 on 1 June 2011, heading for a region of little apparent ocean structure or variability. It was dubbed the "Big Nothing".

WORK COMPLETED

- Built and installed Chi sensors for measurements of ocean turbulence.
- Developed method to synchronize many floats to fall and rise. Each float has a depth vs. time mission in its firmware and makes internal adjustments of fall/rise rates to remain in step.
- Participated in LatMix meeting at UCLA on February15-16 2011.
- Prepared equipment, including new situation awareness system to minimize instrument losses.
- Conducted LatMix field study 1-21 June aboard R/V *Endeavor* Cruise 494 out of Morehead City, NC, serving as Chief Scientist.
- Engaged in data archiving and quality control to provide observations within 6 months.
- Conducted scientific analyses of CTD, velocity and turbulence observations.

Our cruise on the R/V *Endeavor* conducted 3 experiments in conjunction with the joint 3-ship, LatMix experiment. The *Endeavor* program was directed by Jody Klymak using several MVPs, Kipp Shearman with 5 gliders and me with a fleet of 21 EM-APEX floats. We departed Morehead City NC at 0900 1 June 2011. After some MVP and float testing on the way to the "Big Nothing", a region of only weak upper ocean property gradients, we conducted a few legs to the 3-ship survey of the region. The survey confirmed the general weak upper ocean gradient structures.

Late on 3 June we deployed an array of all 21 of the EM-APEX floats at Site 1 in 3 circles of radii 0.5, 1 and 2 km. The Slocum glides were launched at "corners" of the inner circle. The R/V *Cape Hatteras* deployed dye in the center of the float array. There were two varieties of floats: 11 standard floats that measured V, T, S and P and an additional 10 that also measured chi the thermal diffusion rate. Each chi float carried two T variance sensors and conditioning circuit from Rockland Scientific, Inc. The data were digitized on microcomputer board build by APL/UW. The chi-floats were new and had not been tested in the ocean prior to the cruise.

As expected, there were only weak shears and strain in this region. The array gradually evolved into an ellipse with NW-SE larger than NE-SW. The center of the array moved initially to the NW but ended up more than 10 NM to the SE. It was notable that the array remained very coherent, as if they moved together with the low frequency motions. This is consistent with the lack of submesoscale velocity gradients. For most of the time, the MVP was towed in a butterfly pattern with 4, 10-km legs. The MVP tows were interrupted to recover a few floats to reduce the array's ellipticity. It was noticed that the floats exhibit large near-surface velocities that occurred during daylight. Meanwhile, we tuned the float control system to achieve nearly simultaneous profiles on the up cast of all floats. The velocity error was diagnosed as resulting from direct sunlight striking the Ag/AgCl electrodes. To test this hypothesis, a float was recovered and had shading added to a pair of electrodes on one of the two separate electrode channels. The resulting deployment demonstrated that the unmodified channel had spurious near-surface velocities, while the shaded channel did not exhibit the same behavior. Then we began to modify the electrode caps, which are used to keep the electrodes wet when not in the ocean. Essentially, a slot was cut in the cap, such that direct sunlight did not strike the electrodes.

The first location of the experiment allowed for approximately 6 days of EM-APEX profiles occurring roughly every 1.5 hour. For each surfacing, the separation of the floats was calculated and then compiled for the entire deployment. The Fig. 3 is a representation of the separations of the floats when they surface for the entire first deployment. Normalized percentages are plotted (y-axis) with distances binned to 0.1 km (x-axis). Median and mean were calculated to be 2.2 km and 2.6 km, respectively.

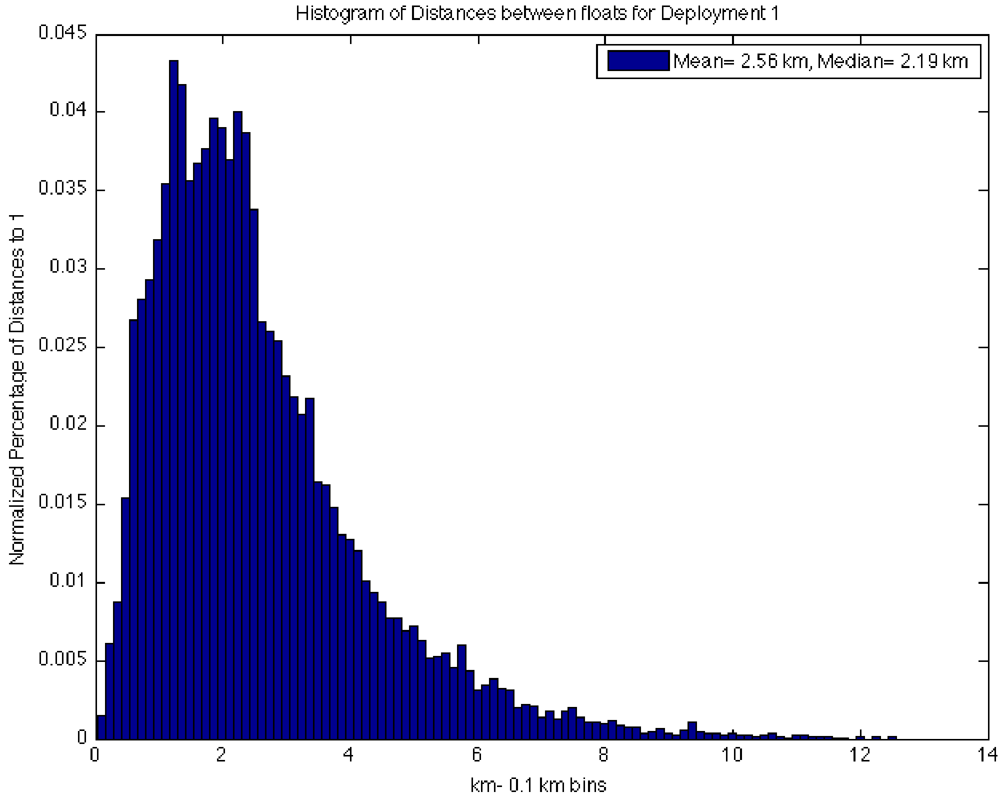

Fig. 3: Histogram of the lateral separat-ions of the EM-APEX floats in the 1st deployment. Similar histograms for the second and third deployments exhibit larger spreads with means of 3.2 and 5.1 km and medians of 2.5 and 4.2 km, respectively.

To evaluate the evolution of the array of floats over the period of the deployment, the Fig. 4 shows the deformation of the float arrangement on the top panel. This is the outer ring of floats connected with a blue line as it evolves from left to right over time. Northwest-southeast shearing of the array begins to occur towards the end of the deployment. In the middle panel, the area of the ring is plotted over this same time period and is seen to be relatively constant at 6-7 km^2 for the time series. The bottom panel for this figure is the perimeter of the float ring and it consistently increases from 10 km to 20 km.

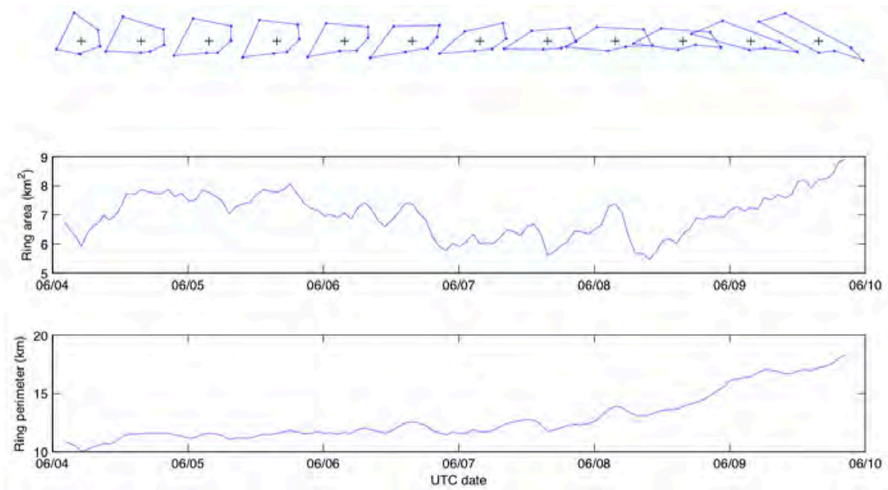

Fig. 4: Top panel. Constel-lations of outer ring of floats during 1st deployment. The float positions are relative to the center of the array. The constellation may be distorted if a particular float in the outer ring did not provide a GPS fix. However, the general pattern of strain is evident. Middle panel: Ring area vs. time. Bottom panel: Ring perimeter vs. time.

It was decided to terminate the observations in the Big Nothing and move North to a region of great strain after about 6 days. The floats were recovered by the R/V *Endeavor* and the RHIBs from R/V *Endeavor* and R/V *Oceanus* on 10 June. All of the EM-APEX floats were fitted with the modified electrode caps to prevent the unexpected sunlight generated electrode offset voltages. In addition to diagnosing the sunlight effect, the chi sensor observations were judged to be OK. The evidence was that noise level observed at depth was much less than the signals of chi patches and that both chi sensors observed very similar features almost all the time. On the other hand, the electric field noise was unexpectedly larger than found on non-chi floats. A clue to the source of the noise was that the zinc anode turned white and the stainless steel shafts of the chi sensor were pitted, no longer shiny. It was noted that the still-shiny shafts exhibited high resistance to the end cap, while the dull-surface units were shorted. Thus, most SS shafts had contact through the threads, but a third did not make contact. It appears that the hard anodize coating on the end cap threads did provide insulation to a few shafts. Only float 4973 had two shiny SS shafts. Unfortunately, this float the electric field channels of this float did not work until repaired for the last deployment. However, the EF noise on that deployment was very low. We conclude that the chi sensor should be insulated from the anodized aluminum end cap.

The Site 2 experiment was located in much larger property gradients. Again, all R/Vs conducted towed CTD and ADCP surveys of the region to assess the property and velocity gradients. The site was chosen to be suitable. Nineteen floats were deployed early on 13 June on radii of 0.25, 0.5 and 1 NM, followed by dye injection. All floats used the electrode caps that prevented direct sunlight from striking the Ag/AgCl electrodes. The strain was evident as the float deployment was distorted just as the circles were executed. There was a rapid change from approximate circularity into much ellipticity. Again, the MVP and Slocum gliders were deployed near the dye site. The evolution of the EM-APEX array was such that it elongated in the N-S direction and narrowed in the E-W. Also, the floats, which profiled over the upper 150 m or so, gradually remained behind as the dye and drogued floats moved northward. The rapid strain necessitated recovery of some floats that were repositioned to maintain a coherent array. Finally, all floats were recovered on 16 June to be redeployed closer to the dye injections that had moved to the north.

The third deployment, one that is within the Site 2 region, was completed late on 16 June. Eighteen floats were deployed in 3 rings of radii 0.5, 1 and 2 NM. Because the dispersion of floats for floats in the second deployment was less than anticipated, the ring radii were doubled. Two were held back for later deployment. By the time the two inner rings were deployed, it was clear that the current was distorting the array, making some floats too close together. So the center of the largest circle was moved north by 2 NM before deployments. This move was successful in providing an initial array over an adequate range of separations. Weather had deteriorated, causing some concern about float, glider and drifter recoveries in a few days. The float array was allowed to remain untouched until recovery early on 20 June 2011.

During the cruise, 9264 CTD profiles were obtained. Of these, 8352 and 2047 were successful profiles of velocity and chi, respectively. Initial quality screening shows that 94% of the CTD profiles also had velocity observations and 87% had useful chi values.

IMPACT/APPLICATION

The use of autonomous vehicles operating in a coordinated way is able to separate temporal and spatial variability. In contrast, observations at a single site consist of fluctuations caused by both time and space dependencies. The use of a swarm of UUVs, all programmed to operate in unison, is now possible and surely will provide much more information than obtained by the more traditional methods. During the field study, over 8,000 CTD and velocity profiles were obtained in three experiments.

TRANSITIONS

The EM-APEX float resulted from a SBIR contract from ONR to Webb Research. This instrument has already begun to have an impact on a variety of experiments. The recent ONR DRI projects that the PI has been involved in have EM-APEX components. Other investigators have purchased and used these floats, such as James Girton, Mike Gregg and Helen Phillips (U. Tasmania).

RELATED PROJECTS

Study of Kuroshio Intrusion and Transport using Moorings, HPIES and EM-APEX Floats (N00014-08-1-0558) as a part of QPE DRI: The primary objectives of this observational program are 1) to quantify and to understand the dynamics of the Kuroshio intrusion and its migration into the southern East China Sea (SECS), 2) to identify the generation mechanisms of the cold dome often found on the SECS, 3) to quantify the internal tidal energy flux and budgets on the SECS and study the effects of the Kuroshio front on the internal tidal energy flux, 4) to quantify NLIWs and provide statistical properties of NLIWs on the SECS , and 5) to provide our results to acoustic investigators to assess the uncertainty in the acoustic prediction. Results of this DRI program will help understand oceanic physical processes on the southern East China Sea, e.g., the cold dome. Typhoons may modulate the Kuroshio, the Kuroshio intrusion, and other oceanic processes and result in cold pools on the continental shelf of the SECS.

Process Study of Oceanic Responses to Typhoons using Arrays of EM-APEX Floats and Moorings (N00014-08-1-0560) as a part of the ITOP DRI. Fourteen EM-APEX floats were air-deployed into two W. Pacific typhoons. *T. Fanapi* was a category 1 tropical cyclone. Seven floats were deployed about a day in front of *Fanapi* in mid-September 2010. Similarly, 7 floats were deployed in front of Super Typhoon Megi in mid-October. All floats survived the deployment and reported profiles. We are studying the characteristics and dynamics of the oceanic response to and recovery from tropical cyclones in the western Pacific Ocean

Studies of the Origins of the Kuroshio and Mindanao Currents with EM-APEX Floats and HPIES (N00014-10-1-0468). This is a component of the Origins of the Kuroshio and Mindanao Currents DRI. We intend to deploy 5 HPIES (Horizontal electric field, pressure and IES) surrounding R-C Lien's surface moorings NE of Luzon Is., probably close to the Balintang Channel. The purpose of the HPIES is to determine barotropic velocity from the electric field and baroclinic velocity from PIES in a triangle around a mooring. The total water column measurements nicely compliment those from the moorings. In addition, EM-APEX floats will be deployed in the NEC as it approaches the Philippine Island and bifurcates into the Kuroshio Current going N. and Mindanao Current flowing S.

HONORS/AWARDS/PRIZES

None